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ESTIMATING MONTHLY PRECIPITATION FROM SATELLITE DATA

by

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ABSTRACT

Monthly precipitation for 5-degree latitude-longitude squares over the United States is related statistically to two parameters; estimates of the albedo of the ground and of the entire earth-atmosphere system. The latter are represented by macro-scale brightness data from Taylor and Winston (1968).

The method yields only fair results when applied to independent data for Europe and Africa.

Improvements may be realized if sufficient data can be obtained so that they can be subdivided by geography and season, and if two other satellite products beside albedo are added as parameters. These are the relative frequencies of cumiliform and stratiform clouds, and of the different circulation types.

1. Introduction

In an earlier report (Clapp, 1970) an empirical method was described for estimating monthly-mean cloudiness, and for modifying a short-wave radiation formula, based on macro-scale brightness data derived by Taylor and Winston (1968) from the ESSA weather satellites. These data are averages of the individual video brightness for all 5-degree latitude-longitude "squares" over most of the Earth, for each month of the period February 1967 to February 1968 inclusive.

The reader must be referred to the earlier report for a complete discussion of the data processing. This involved the determination of mean cloudiness and surface (ground) albedo for 25 5-degree squares over land areas of the contiguous United States (U.S.) for each of the 13 months. These were then used in conjunction with the corresponding brightness data (referred to hereafter as "brightness levels") to test and modify the radiation formula.

The brightness level for a given month and 5-degree square was adjusted by Taylor and Winston so that it is a function of the albedo (reflectivity) of the earth-atmosphere system (as distinct from the absolute brightness), which in turn depends on solar and sky radiation reflected or scattered back to space from the earth's surface, clouds and atmosphere. Since the fraction of incoming radiation scattered back to space by the clouds depends on cloud amount, thickness, and structure, an attempt was made to relate the brightness levels to precipitation as well as to cloudiness.

The part of the study dealing with precipitation is summarized in this report. The immediate objective is to estimate monthly precipitation amounts over the oceans, where observations are as yet almost totally lacking. Among other considerations, such observations are needed in testing global numerical models designed for extended and long-range forecasting, because this quantity almost determines the heat of condensation, an important element of the atmospheric heat budget.

2. Data processing and discussion of results

The average precipitation was determined for each of the 325 months and 5-degree squares. This was done in two steps, using as the data base monthly precipitation charts for the U. S. on file in the Extended Forecast Division (Namias, 1953) and analysed by 3 rainfall classes (light, moderate and heavy). First, an estimate was made by eye of the fraction of a certain square occupied by each class. Then the average precipitation for each class was estimated using the precipitation data observed at the weather stations and plotted on the chart. The average precipitation (P) is then:

$$P = P_1 f_1 + P_2 f_2 + P_3 f_3$$

Where the P's and f's are respectively the average precipitation and fractional area for each of the 3 classes, where the numbers 1, 2 and 3 are assigned to the classes light, moderate and heavy, respectively.

This procedure was preferred over the alternate method of averaging the precipitation over each square. This latter procedure would have required a laborious re-analysis of the precipitation charts in terms of total amount, which is very difficult on account of the wide separation of the stations and strong geographical variations in precipitation. On the other hand, the chosen method may have resulted in some gross errors, despite it's obvious economy in computing time.

Since the albedo of the earth-atmosphere system depends on the surface (ground) reflectivity as well as on the cloud albedo, the average precipitation was related statistically to the first two of these parameters (the first being represented by the brightness levels) using a well-known contingency-table technique (Panofsky and Brier, 1958) which is roughly equivalent to multiple curvilinear correlation between one dependent and two independent variables. The entire data sample of 325 cases was used.

The results are shown in Table 1. It will be noted that 7 categories (classes) of brightness level and 5 of surface albedo were chosen. In order to obtain reasonably-spaced class limits it was not possible to select the limits so that equal numbers of cases were obtained in each "box". (A "box" consists of the data within each class interval of brightness level and surface albedo.)

It will be noted (top number in each box) that precipitation tends to increase with brightness level within each class of surface albedo. However, with the exception of the lowest surface albedo class, the highest category of brightness level shows a decrease in average precipitation. This reversal could result from sampling errors due to the very small number of cases (lowest number in each box) in the extreme brightness-level classes. However, this seems unlikely, since the same result is found in 4 of the 5 surface albedo classes. Perhaps this reversal is caused by a change in cloud type. The brightest cloud masses, when averaged over a whole month, may consist of relatively long-lasting thick stratiform types. Cumiliform types, which produce most of the precipitation in summer, are more transient and widely scattered, and although they have a high albedo, much of the reflected radiation is lost through multiple reflection between clouds and between clouds and ground.

Another interesting finding is the sharp decrease in average precipitation as the surface albedo increases. This no doubt is caused by variations in local climate and season; because higher surface albedoes are associated with dry grasslands or semi-deserts, or with cold snow-covered areas where total precipitation tends to be small. Unfortunately, the small numer of cases in the boxes of Table 1 show clearly that the data sample is far too small to justify further subdivision by season or geographical area.

The large variability of precipitation within each box is brought out clearly by the range of values within which the central 1/3 of the cases fall (middle numbers in each box having 6 or more cases). In several instances there is considerable overlapping of the ranges for adjacent boxes. This finding raises a serious question about the practical utility of these results in estimating precipitation. This question might be resolved by applying a significance test to the dependent data in the table.

However, instead of doing this, it was decided to carry out a test using independent data for a few selected areas outside the U. S.

Four 5-degree squares were selected over Europe and one over equatorial Africa (see first 2 columns table 2) to represent different climates, and for each locality the average precipitation (last column, Table 2) was estimated for 4 of the 13 months, using the monthly data published by the World Meteorological Organization (1967-68) as mapped by the Free University of Berlin (1967). This observed precipitation is simply an average of all plotted data within the square; occasionally augmented by some data outside of, but close to, the boundaries when data were sparse. The results are probably not as representative of the true average precipitation within a given square as those for the U. S.

The surface albedo was computed in a fashion similar to that for the U. S. (Clapp, 1970, formula 2); i.e. as a function of the albedo with and without snow, and the frequency of snow on the ground during the month. The latter was taken as its climatological value (Dickson and Posey, 1967) rather than its observed value for the particular month.

In order to express the precipitation as a continuous function of brightness level and surface albedo, the data in Table 1 were plotted and analysed, with strong smoothing, in a graph (Figure 1). The estimate of precipitation was obtained by entering the graph with the brightness level (read from the charts of Taylor and Winston, 1968) and the corresponding surface albedo. The results for the 20 independent cases are listed in the next to last column of Table 2 and are plotted against the observed precipitation (last column) in Figure 2.

It can be seen from Figure 2 that the overall relationship is only fair (linear correlation coefficient + 0.48 for all 20 cases), no doubt due in part to the restriction that only two quantities (the two albedoes) were used as independent parameters. Probably the main fault lies with the necessity of lumping together all geographical areas and seasons.

When the 5 cases having a 10% or greater frequency of snow on the ground are separated from the others, the correlation coefficient (+0.54 for 15 cases) improves somewhat. Even more surprising is the good results for the 4 cases at the equatorial locality (correlation coefficient +0.88). Of course, this unexpected result may be merely due to a sampling error. One should expect computations based on U. S. data to give too low values in the intertropical convergence zone, on account of the special radiation-scattering properties of the prevailing cumuliform clouds (as suggested previously) which leads to low values of brightness level. In fact, a comparison was made of precipitation estimates, using Figure 1, with those of Barrett (1970) for the month of July 1966 in the tropics near Australia. This indicates that the values from Figure 1 are much too low, even when allowance is made for the fact that the Taylor-Winston brightness levels were taken as those for the following year (July, 1967), and that Barrett's estimates (based on ESSA nephanalyses) are point values and not areal averages.

3. Conclusions

This study summarizes an attempt to estimate monthly precipitation from measures of local albedo obtained from satellite video data over the contiguous United States. The results are not too successful when applied to independent data for Europe and Africa.

Two ways of improving the estimates are suggested: If measures of the albedo of the earth-atmosphere system can be made available on an operational basis, then a large amount of data will quickly accumulate so that separate results can be obtained for a variety of local climates: i. e. The data can be subdivided by geography and season.

Secondly, the study by Barrett (1970) suggests that improvements will result if, in addition to albedo (or total cloudiness), two other satellite products can be made available; namely, the relative frequencies of cloud and circulation types.

After these improvements have been achieved, questions will still remain about the validity of applying the results to ocean areas, as long as precipitation observations continue to be made only at continental or island stations. This problem of the comparability of land and ocean observations has long plagued those attempting to estimate precipitation over the sea (e. g. Möller, 1951). Perhaps it will be necessary to await the development of new generation satellite instrumentation containing radar or other systems for estimating atmospheric water in liquid and solid form.

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TABLES

Table 1.--Mean monthly precipitation for certain classes of brightness level and surface albedo. Top number in each box is precipitation in tenths of inches; middle, range within which central 1/3 of cases fall; and bottom, number of cases.

Table 2.--Estimated precipitation and other parameters for selected 5-degree latitude-longitude squares and months. Symbols are: BL, brightness level times 10, from Taylor and Winston (1968); α_0 and α_5, surface albedo in percent without and with snow on the ground; f_s, climatological frequency in percent of days with one inch or more of snow on the ground; α, computed total surface albedo; P_c and P_o, computed and observed monthly precipitation, respectively, in tenths of inches.

FIGURES

Fig. 1--Monthly precipitation as a function of brightness level and surface albedo. Smoothed analysis from data of Table 1. Curves labeled with average surface albedo (percent) for the 5 classes in Table 1. Dashed 5 percent curve extrapolated.

Fig. 2--Observed vs computed monthly precipitation. Open circles are for the 4 months at 5-10°N, 0-5°W; crosses, 5 cases with 10% or more days with snow on the ground; dots, all other extratropical cases.

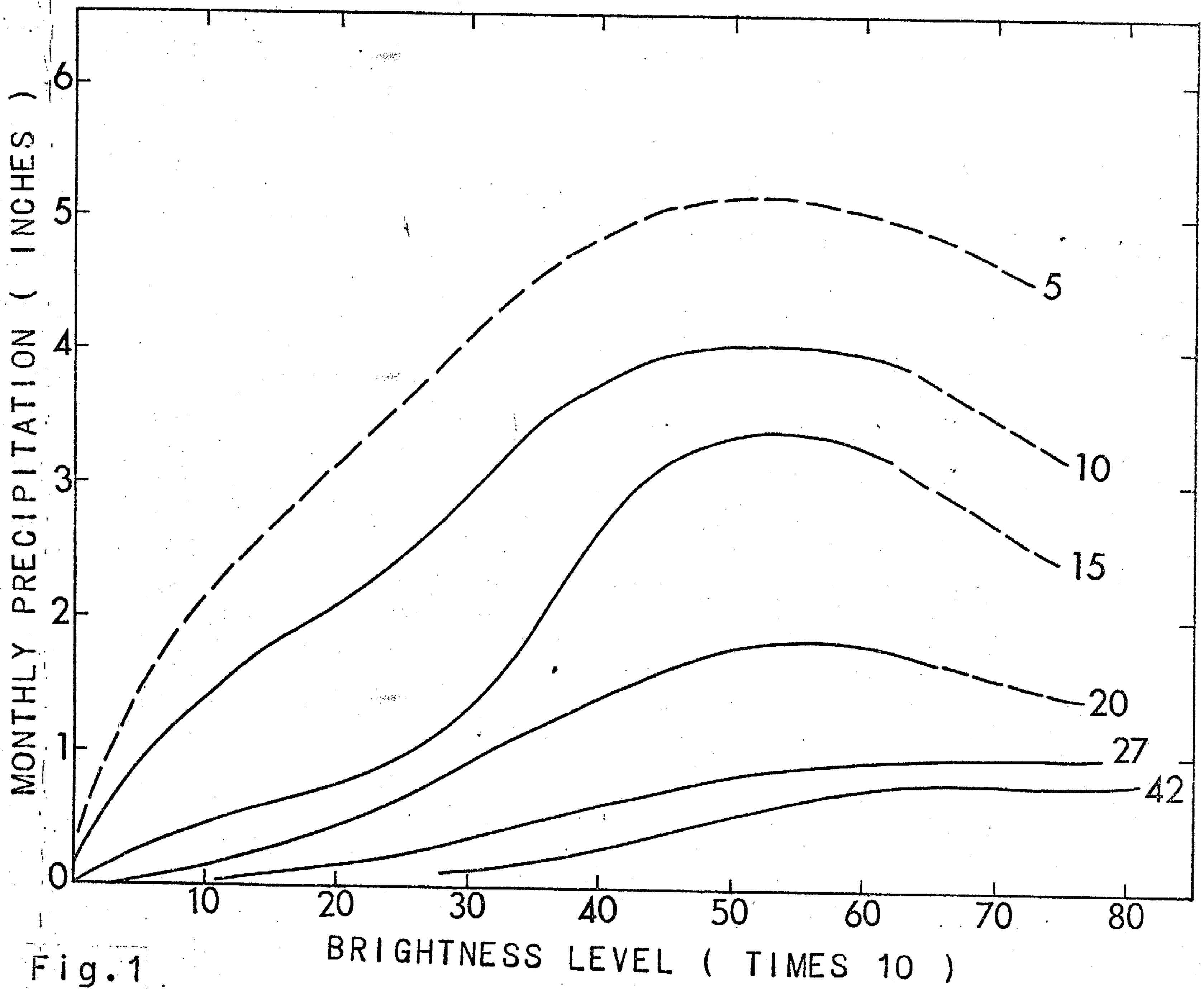
Table 1

Range in Brightness Level (BL x 10)

Range in Surface Albedo (percent)	0 - 20	21-30	31-40	41-50	51-60	61-70	71-90	Average Total
8-12	15 - 4	26 18-28 37	35 23-40 48	40 32-41 20	41 - 5			33 114
13-17	5 2-6 11	11 7-11 24	10 9-12 18	34 27-36 21	33 - 5			18 79
18-22	2 0-2 6	8 4-10 18	10 6-9 25	15 8-18 15	19 7-23 7	16 - 2		11 73
23-32		10 - 2	6 - 2	12 7-7 8	9 8-10 12	13 10-10 8	10 - 4	11 36
33-52			2 - 1	5 - 2	10 8-8 6	10 7-10 9	8 - 5	9 23
Average	6	17	23	28	19	12	8	20
Total	21	81	94	66	35	19	9	325

Table 2

5° Square North Lat.	Long.	1967 Month	BL	α_o	α_s	f_s	α	P_c	P_o
5-10	0-5W	Feb.	13	7		0	7	21	14
45-50	5-10E	Feb.	51	13	48	32	24	11	17
40-45	20-25E	Feb.	52	12	48	13	17	28	11
50-55	20-25E	Feb.	75	16	52	42	31	08	18
50-55	0-5W	Feb.	53	15	35	5	16	31	23
5-10	0-5W	Apr.	30	7		0	7	36	48
45-50	5-10E	Apr.	50	13	48	10	17	28	17
40-45	20-25E	May	38	12		0	12	32	23
50-55	20-25E	Mar.	63	16	52	22	24	12	18
50-55	0-5W	Apr.	56	15	35	1	15	34	13
5-10	0-5W	Jul.	32	7		0	7	38	41
45-50	5-10E	Jul.	31	13		0	13	21	22
40-45	20-25E	Aug.	19	12		0	12	15	11
50-55	20-25E	Jul.	28	16		0	16	10	14
50-55	0-5W	Jul.	49	15		0	15	33	19
5-10	0-5W	Oct.	26	7		0	7	32	23
45-50	5-10E	Oct.	37	13	48	6	15	23	15
40-45	20-25E	Oct.	22	12		0	12	16	13
50-55	20-25E	Oct.	35	16		0	16	17	17
50-55	0-5W	Oct.	42	15		0	15	29	62



MONTHLY PRECIPITATION (INCHES)
0
1
2
3
4
5
6
10
20
30
40
50
60
70
80
BRIGHTNESS LEVEL (TIMES 10)
5
10
15
20
27
42

Fig.1

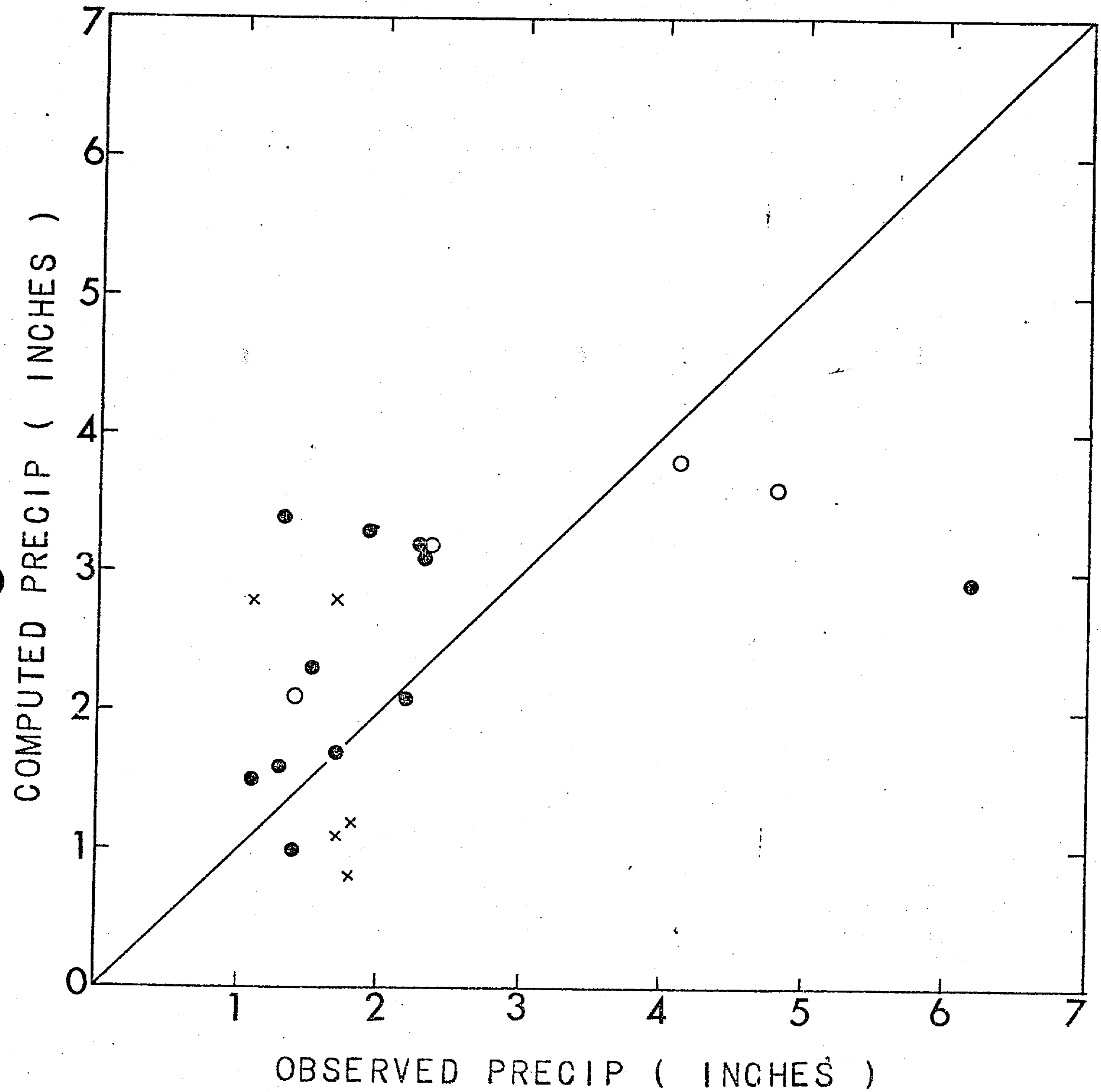


Fig.2